# VACUUM SEAL

This application claims the benefit of U.S. Patent Application 60/125,493, filed March 22, 1999 and entitled "Vacuum Seal", the disclosure of which is incorporated by reference in its entirety herein.

This invention relates to seals, and more particularly to metallic vacuum seals.

A variety of vacuum seal configurations exist. Vacuum seals are commonly held under compression between two opposed flanges of the elements being sealed to each other. Vacuum seals may be used in a variety of industrial applications including semiconductor fabrication and processing.

One basic vacuum seal is formed substantially as a large flat washer of a soft, malleable, metal such as copper. An example of this seal is sold by Varian Vacuum Products Lexington of Lexington, Massachusetts, USA under the trademark CONFLAT. Such a seal may be used with flanges having an annular machined knife edge. When the seal is compressed between the flanges, the knife edges embed into the seal to provide the sealing. The flanges must be hard and strong enough to withstand the necessary compression force. This type of seal has little tolerance for relative motion of the flanges.

Another class of metallic vacuum seals is the so-called c-seal. This is an annular seal of generally c-shaped cross-section which can compress between the flanges to be sealed. An advanced version of the c-seal is sold by EG&G Pressure Science, Inc. of Beltsville, Maryland, USA under the trademark ALPHA. The ALPHA seal utilizes a relatively stiff core member plated with relatively malleable silver to provide improved sealing with the flanges. A somewhat similar seal is disclosed in U.S. Pat. No. 4,261,584.

An enhanced metal seal is sold by Helicoflex of Columbia, South Carolina, USA under the trademark HELICOFLEX DELTA. A similar seal is disclosed in U.S. Pat. No. 4,561,662. The DELTA seal has two metallic jackets surrounding a tightly wound helical spring which provides the seal with longitudinal elasticity. The inner jacket, or lining, may be formed of stainless steel or a superalloy. The outer jacket is made of a more ductile material such as aluminum and has a pair of machined delta-sectioned knife edges for engaging the respective flanges. When the seal is compressed between the flanges, the delta edges are crushed to seal against the flanges.

In one aspect, the invention is directed to an annular metallic vacuum seal having a nested inner and outer c-sectioned members. The inner member provides longitudinal compression strength and elasticity and the outer member has a pair of oppositely-directed ridges for sealing with a pair of flanges.

One of the advantages of the invention is that the seal is relatively easy to clean, particularly for those surfaces on the low pressure side of the seal. The presence of crevices or other hard to clean areas on the vacuum side may be minimized.

The longitudinal elastic compliance provided by the inner member and the longitudinal plastic compliance provided by the outer member may combine to provide an excellent seal between mating flanges at relatively low compressive forces which reduces the need to make the flanges out of ultra high strength material and of robust dimensions while also reducing the number of bolts needed to maintain compression between the flanges. Preferred leakage rates are less than $8x10^{-13}$ $cm^3$/s-mm under standard conditions utilizing a helium mass spectrometer to monitor leakage.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

FIG. 1 is a top plan view of a seal according to principles of the invention.

FIG. 2 is a cross-sectional view of the seal of FIG. 1, taken along line 2-2.

FIG. 3 is a cross-sectional view of the seal of FIG. 2, shown compressed between mating flanges.

FIG. 4 is a top view of an alternate seal according to principles of the invention.

FIG. 5 is a cross-sectional view of the seal of FIG. 4, taken along line 5-5.

Like reference numbers and designations in the various drawings indicate like elements.

FIG. 1 shows a vacuum seal 20 for maintaining a seal between first and second opposed flanges (not shown) to maintain an internal pressure less than an external pressure. The seal is of generally annular configuration, being angularly symmetric about a central longitudinal axis 500. When viewed in longitudinal radial section (*i.e.*, along a central longitudinal plane 501 outward from the axis 500) the seal is generally c-shaped and open radially outward (FIG. 2).

The seal is substantially symmetric about a transverse centerplane 502. The seal has nested inner and outer members or jackets 22 and 24, respectively. Both are generally c-shaped and open radially outward. The inner member has inner and outer surfaces 26 and 28 joined by edge surfaces 30A and 30B. The outer member has inner and outer surfaces 32 and 34, respectively. In FIG. 2, a line 503 (a cylindrical construct when not viewed in cross-section) designates the radial location of the maximum longitudinal span of the inner member 22. Proximate the annular ends of the outer member 24, the outer member includes longitudinally-projecting protuberances 40A and 40B which provide annular ridges. These protuberances project slightly beyond the adjacent portions of the outer surface 34. The longitudinal extremities 42A and 42B of the ridges 40A and 40B engage the adjacent flanges 100A and 100B (FIG. 3) to form a seal and may be exactly or nearly coaligned with the line 503. The outer member 24 need not extend substantially radially beyond the line 503. Viewed relative to the intersection of the line 503 and plane 502, this may be from a few degrees to about 20 degrees beyond the line 503. The inner member advantageously extends slightly farther therebeyond, e.g., to an exemplary 30° beyond the line 503. The inner member 22 provides the primary structural integrity of the seal and is formed of a material and with dimensions effective to maintain compressive engagement with the flanges. This will be achieved by making the inner member substantially thicker than the outer member. A preferred material for the inner member is sold by INCO Alloys International, Inc. under the trademark INCONEL Alloy 718. Other "superalloys" having a nickel base and significant amounts of iron and chromium (for corrosion resistance) may also provide advantageous performance. High strength, high gall-resistance stainless steels such as that sold under trademark ULTIMET by Haynes International, Inc. of Kokomo, IN may also be used. A preferred material for the outer jacket is aluminum 1100 (99.0% Al minimum), a substantially pure aluminum. Various aluminum alloys may also be utilized as can other ductile metals.

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In an exemplary nominal three inch (7.62 cm) diameter seal (measured as a minimum diameter $D_1$ of the longitudinal opening within the outer member 24 at the plane 502) the inner member may have a relaxed longitudinal length $L_2$ of about 0.16 inches (0.41 cm) and a thickness of about 0.024 inches (0.061 cm). A broader thickness range is 0.015-0.035 inches (0.038-0.089 cm). The ridges may have a longitudinal extent $L_3$ of about 0.005 inch (0.013 cm). A thickness of the outer member (away from the ridges) may be about 0.01 inches (0.025 cm), a thickness well under half the exemplary thickness of the inner member. A broader thickness range is 0.005-0.020 inches (0.0123-0.051 cm). The radial extent or span $S_1$ of the

outer member may be about 0.10 inches (0.25 cm). The ridge extremities 42A and 42B form a pair of flat annuli with a radial span $S_3$ of about 0.006 inches (0.015 cm). The longitudinal span $L_1$ of the outer member at the line 503 between the extremities 42A and 42B may be an exemplary 0.19 inch (0.48 cm). When compressed between opposed flat annular surfaces 102A and 102B of flanges 100A and 100B, the ridges are both plastically and elastically deformed to form a seal and the inner member is plastically and elastically longitudinally compressed (e.g., by about 0.044 inch (0.11 cm) so that compressed overall and inner member lengths $L_1'$ and $L_2'$ are about 0.16 inch (0.41 cm) and 0.14 inch (0.36 cm) to bias the ridges into engagement with the flanges. An exemplary compressive engagement force on the seal is 400-1000 lbs/inch (7-17.5 N/m) of contact length (seal circumference at the ridges).

An exemplary process for production of the seal is as follows. Strip stock of the material for the inner member is cut to correct length and width. The ends of the strip stock are welded together to form a hoop or band. The band is then roll formed to circularize it. It is then die formed to produce the basic c-shaped section. It is then heat treated to increase strength. It is then cleaned and electroplated with copper or other decorative/appearance enhancing-material. Alternatively, instead of plating, the jacket may be electropolished.

To prepare the outer jacket, aluminum is advantageously cold drawn to provide a long tubular body which is then cut longitudinally to form bands. This avoids the difficulties of welding aluminum. Alternatively, the band may be formed by welding ends of a strip (e.g., by laser, tungsten inert gas (TIG), electron beam (EB), and the like). One such band is then placed radially within the inner jacket and roll formed to wrap it into the c-shaped section around the inner jacket. Then, a second roll step forms the ridges. The seal is then flat lapped to provide the ridges with the desired degree of parallelism, planarity, surface uniformity, and longitudinal separation. Finally, the seal is cleaned and packaged in contamination-resistant packaging.

FIGS. 4 and 5 show an alternate embodiment of a seal 120 having nested inner and outer members 122 and 124, respectively. The outer member 124 may be substantially identical to the outer member 24 and its portions are not, therefore, referenced with distinct numerals. The inner member 122 has inner and outer surfaces 126 and 128 adjoined by edge surfaces 130A and 130B. The inner member 122 is formed having a central arcuate portion 150 and a pair of distal straight portions 150A and 150B extending from opposite ends of the arcuate portion. The distal portions are oriented substantially parallel to each other directed radically outward so as to provide a pair spaced-apart flat flanges. The distal portions extend beyond the line 503 by a distance which is a significant fraction of the total radial span of the

inner member. An exemplary distance would be between about a third and a half of this span. Preferred dimensions of an alternate embodiment of the alternate size of the exemplary seal 120 are $D_1$=40.579 inches (103.07 cm); $S_0$=0.177 inch (0.45 cm); $S_1$=0.117 inch (0.30 cm); $L_1$=0.241+/-0.010 inch (0.612+/-0.025 cm); $L_2$=0.194+/-0.004 inch (0.493+/-0.010 cm); $L_3$=0.009-0.014 inch (0.23-0.36 cm). The inboard transition between the ridges and the adjacent outer surface of the outer member is radiused to about 0.01 inch (0.025 cm) and the outboard radial ridges are chamfered to an angle of about 45 degrees by 0.005 inch (0.013 cm). The inner jacket is formed from strip stock 0.0300+/-0.0010 inch (0.0762+/-0.0025 cm) thick and 0.405+/-0.003 inch (1.029+/-0.008 cm) wide. The outer member is formed from strip stock 0.0120+/-0.0005 inch (0.0305+/-0.0013 cm) thick and 0.402+/-0.002 inch (1.021+/-0.001 cm) wide. For such a seal, compressed overall and inner member lengths $L_1'$ and $L_2'$ would be about 0.197-0.199 inch (0.500-0.505 cm) and 0.173-0.175 inch (0.439-0.445 cm).

One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, various dimensions and properties may be chosen to adapt to a particular environment and may be selected to form the seal as a drop-in replacement for existing seals. Accordingly, other embodiments are within the scope of the following claims.

Unless noted otherwise, wherever both English and metric units are given for a physical value, the English units shall be assumed to be the original measurement and the metric units a conversion therefrom.